Research Programme: Improved Prediction of Wind Induced Building Motion

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Abstract

We have recently begun a 3-year research programme which aims to achieve improved prediction of wind induced motion of tall buildings. This is a collaborative programme involving Opus Central Laboratories, Auckland University Department of Mechanical Engineering, Steel Construction New Zealand, and Building Research Association of New Zealand.

Structural designers currently have reservations about the accuracy of building response predictions, and often take a conservative approach by making the buildings heavier in order to resist wind excitation, or make provision to add damping systems to limit building motion. The research is intended to provide design certainty for the construction industry that multi-storey buildings will not sway in the wind to an extent that is disturbing to the building occupants.

Components of the research will include:

- On-site monitoring of wind induced motion of several existing tall buildings
- Wind tunnel model studies of the selected buildings
- Achieving an improved procedure for analysis of wind induced building motion

This paper describes the background and various elements of the planned research.

Introduction

Serviceability design of buildings for wind relies solely on analytical and scaled models, which are based on fundamental mechanics and years of research experience. However these have not been systematically validated in full-scale, particularly for lower buildings in urban settings. The code requirements (such as AS/NZS 1170.2:2002, which has strict criteria around the point at which dynamic effects must be calculated) necessitate potentially expensive design procedures on certain types of low-medium rise buildings to assess whether the design is able to withstand both wind and seismic effects. Buildings with increased aspect ratios are susceptible to wind effects but generally fall outside the range of loading data provided by codes and wind tunnel tests when serviceability performance is considered for less than 1–5 year return period wind speeds. For such conditions, wind loading data has to be extrapolated and often results in predicted building responses that appear unrealistically large for the size of the building. As extrapolation is involved, structural designers have considerable reservations about the accuracy of the building response predictions and often take a conservative approach by making them heavier than desirable to resist wind excitation, or make provision to add damping systems to limit motion whenever wind motion discomfort is indicated. The proposed research has been formulated to dispel these reservations and to provide design certainty for the New Zealand construction industry that multi-storey buildings will not sway in the wind to an extent that would be disturbing to the building occupants. The buildings of interest are typically in the size range 10 to 40 storeys.

Background

A body of evidence is emerging in New Zealand that even moderately sized multi-storey buildings (e.g. 10 storeys) can be susceptible to wind-induced building motion that is disturbing to building occupants. This was not expected by the industry and may be the result of lightweight construction systems being used and /or a need to better account for the spatial distribution of wind loads acting on a building in the design process.

Existing code and wind tunnel based procedures are based on wind force spectra whereby the dynamic response of a building is estimated from the wind energy available in very narrow bands about the natural sway and torsion frequencies of the building. However, significant discrepancies between predicted and actual building sway have been reported for some cases, particularly for the cross-wind direction where code predictions have been found to be not very reliable. This is attributed to either the adequacy of the spectral method or to the accuracy of the cross-wind spectra incorporated into wind codes and standards or a combination of both.

Specific concerns with the cross-wind spectra the Australian/New Zealand wind loading standard AS/NZS 1170.2:2002 are that they cover a very limited range of simple shapes and that they lie outside the range required for analysis of short-period return winds necessitating use of extrapolated values. Also, these cross-wind spectra have been indirectly derived from aero-elastic model studies performed in the early 1970's and appear to be overly-conservative for low aspect ratio buildings when serviceability (short-period) level winds are considered. The evidence for this is that the magnitude of the cross-wind spectra are shown to be independent of building aspect ratio for short-period return winds but very dependent on building aspect ratio for long-period return winds. This is counter to the expectation that the dependency should be invariant with wind speed.

Figure 1 shows the reduced velocity range for serviceability calculations for the typical buildings of interest. It is plotted over cross-wind force spectra from the wind loading standard. We have chosen to show the spectra as plotted in the 1989 wind loading standard. In the 2002 standard, the spectra have been redrawn, and consequently have a somewhat different appearance, but are otherwise essentially the same. It is apparent that the reduced velocity range for the buildings of interest is outside of the data range provided in the standard.

Research Programme

A 3 year programme of research has been formulated to provide design certainty to prevent wind-induced swaying of multi-story buildings that is disturbing to occupants. It will include three tasks as follows:

1. Measurement of wind-induced motion of selected existing buildings located in Auckland and Wellington.
2. Comparison of the measured building motion with results from existing New Zealand loading standard and wind tunnel procedures to establish the adequacy of the wind force spectra approach.
3. Development of a validated methodology for wind design of buildings to achieve satisfactory occupant comfort and building serviceability that can be incorporated in the New Zealand loading standard. This will involve either generating more detailed cross-wind force spectra for a larger range of building aspect ratios for use with the spectral method or the formulation of time history or semi-empirical based calculation procedures.

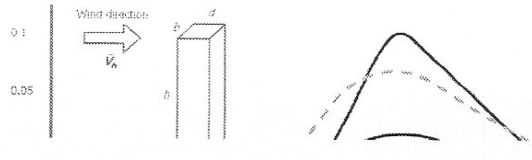

Figure 1. Reduced velocity range for typical buildings of interest, shown with loading standard spectra

The technical objectives of the research are to:

1. Validate the wind spectra based procedure for calculating building accelerations under serviceability wind conditions and investigate alternative procedures if necessary and
2. Extend existing wind load design information in the Australasian wind loading code to cover low reduced velocities.

The aim is to achieve greater design certainty for dynamic wind effects acting on multi-storey buildings located in city environments leading to safer and more cost-effective building construction.

A scientific approach will be taken that involves full-scale monitoring of buildings in Auckland and Wellington and retrospective modelling of the monitored situations using code, wind tunnel test and numerical simulation procedures to establish the degree of agreement between predicted and observed building accelerations. The results of this comparative exercise will establish whether existing code procedures should be retained and enhanced or an alternative procedure developed.

The research will addresses the question of why, in the current Australasian/New Zealand wind loading standard, there is a congruence of the loading spectra for buildings of significantly different shape and aspect ratio at low reduced velocities. There is no readily apparent reason for this congruence based on our experience and review of public domain literature, which raises doubts as to the reliability of the code calculations for serviceability wind conditions. Therefore, the research will significantly advance our knowledge of wind loading mechanisms on moderate height multi-storey buildings in city environments leading to more reliable methods for predicting their affect at the design stage.

Task 1: Detailed Monitoring of Wind Induced Building Motion

Detailed on-site monitoring of 3 buildings located in Wellington and Auckland will be performed so that key structural systems currently being used in New Zealand for multi-storey buildings will be covered. The structural systems investigated will be drawn from:

- Steel frame with precast hollow core flooring
- Concrete frame with precast hollow core flooring
- Concrete shear wall with precast hollow core flooring
- Concrete frame with insitu cast flooring
- Steel frame with insitu cast flooring

Monitoring will determine the relationship between wind conditions and the response characteristics of buildings (deflections, accelerations and rotations). The monitoring will allow determination of structural characteristics (e.g. sway frequencies, damping and mode shapes) for validation of structural models. The specifications of the instrumention used will be comparable to that of the Chicago Full Scale Monitoring Project [1].

Task 2: Wind Tunnel Model Studies

Wind tunnel testing, involving simultaneous pressure [2] and high-frequency force balance [3] measurements, will be performed on scale models of the three monitored buildings. The wind tunnel pressure measurements will be undertaken at Auckland University and used as input to the structural analysis programme ETABS (regarded as the industry standard for building analysis and design) to allow comparison of measured and predicted temporal responses for wind events causing significant building movement. The model pressure measurements will also be used to investigate local wind forces in terms of mean and rms force coefficients, power spectral density, and spanwise correlation and coherence.

Overall base moments obtained by integrating the pressures will be compared with results of high-frequency force balance tests made at both Auckland University and Opus. This will allow the validity of the linear-mode shape assumption of the force-balance test to be assessed; investigation of model scale and tunnel speed trade-offs to obtain force spectra at the very low values of reduced velocity required for New Zealand buildings; and most importantly harmonisation of the two wind tunnel test facilities.

Task 3: Validated Methodologies for Serviceability Wind Design

The spectral method in AS/NZS 1170.2 will be applied to the three buildings monitored using the cross-wind spectra derived from the high-frequency force balance tests in Task 2. Emphasis will be placed on cross-wind loading as this has been found to dominate the wind response of medium - height buildings located in urban areas when serviceability (short-period) level winds are considered. This will establish if more accurate spectral information over the range required for serviceability analysis will result in sufficient agreement between observed and predicted responses for structural design purposes. Should this prove to be the case, additional high-frequency balance tests will be undertaken to generate detailed cross-wind spectra for a range of building aspect ratios for incorporation in AS/NZS 1170.2.

If not, other candidate methods for wind standards such as Lin et al's [4] empirical expressions for force spectra and spatial correlations, and Cenek et al's [5] regression based model presently adopted by HERA, will be applied to the three buildings wind tunnel tested in Task 2 to investigate what level of agreement between predicted and observed responses can be achieved.

The aim is that the research will lead to a design procedure that readily and reliably assesses a building with regard to wind-induced vibration serviceability criteria. The easier such a technique is to apply, the more likely it is to be correctly implemented. Any proposed changes to the existing procedures identified by the research will be exposed to scrutiny by the design industry prior to being recommended for incorporation in AS/NZS1170.2.

References

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